

Naval Research Laboratory

Washington, DC 20375-5320



NRL/MR/8150--97-8117

Quantic Global Positioning System Timing Receiver Live Static Test

EDWARD D. POWERS

EDWARD C. JONES

JIMMIE BRAD

*Space Applications Branch
Space Systems Development Department*

December 2, 1997

DTIC QUALITY INSPECTED

Approved for public release; distribution is unlimited.

19971208 046

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188
<p>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.</p>			
1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED	
	December 2, 1997		
4. TITLE AND SUBTITLE			5. FUNDING NUMBERS
Quantic Global Positioning System Timing Receiver Live Static Test			
6. AUTHOR(S)			
Edward D. Powers, Edward C. Jones, and Jimmie Brad			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)			8. PERFORMING ORGANIZATION REPORT NUMBER
Naval Research Laboratory Washington, DC 20375-5320			NRL/MR/8150--97-8117
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSORING/MONITORING AGENCY REPORT NUMBER
746th Test Squadron 46th Test Group Holloman AFB, New Mexico 88330-7850			
11. SUPPLEMENTARY NOTES			
12a. DISTRIBUTION/AVAILABILITY STATEMENT			12b. DISTRIBUTION CODE
Approved for public release; distribution unlimited.			
13. ABSTRACT (Maximum 200 words)			
<p>The GPS Program Offices, Los Angeles Air Force Base, California, has established a Center of Expertise (COE) comprised of several agencies, each providing unique GPS test capabilities for the purpose of developing a Commercial Receiver Test Program (CRTP). The Responsible Test Organization (RTO) for the COE is the 746th Test Group, 46th Guidance Test Squadron, Holloman Air Force Base, New Mexico.</p> <p>The Naval Research Laboratory (NRL) has been designed as a COE with the responsibility of testing the time output characteristics and accuracy of the commercial receivers. The NRL clock testing facility has time traceable to the U.S. Naval Observatory and the procedure used are taken from the CORE INS/GR/EGI TEST PLAN prepared by RTO.</p>			
14. SUBJECT TERMS			15. NUMBER OF PAGES
Satellite Timing			GPS receiver 31
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

CONTENTS

DIAGRAMS	v
TABLES	vi
GRAPHS	vii
EXECUTIVE SUMMARY	viii
1. INTRODUCTION	1
1.1 Test Item Description	1
2. TEST OBJECTIVES	2
2.1 Performance Evaluation, Specifications, Test, And Document Paragraph Matrix	2
3. TEST DESCRIPTIONS	3
3.1 Position	3
3.2 Time Accuracy	3
3.3 1PPS Output	3
3.4 Spurious And Harmonic Content	3
3.5 Phase Noise Measurements	3
3.6 Frequency Accuracy	3
3.7 Fractional Frequency Stability	3
4. TEST RESULTS	3
4.1 Position	4
4.2 Timing Accuracy	4
4.3 One Pulse-Per-Second Output	4
4.4 Spurious And Harmonic Content	5
4.5 Phase Noise Measurements	5
4.6 Frequency Accuracy	5
4.7 Fractional Frequency Stability	6
4.8 Conclusions	6
Appendix A	7
MEASUREMENT METHODS	7
A.1 TIME CALIBRATION	7
A.2 ANALYSIS AND MEASUREMENTS	8
A.3 LIST OF TEST EQUIPMENT	8

Appendix B	11
TGR SPECIFICATIONS	11
B.1 SELF SURVEY ACCURACY	11
B.2 TIMING ACCURACY	11
B.3 ONE PULSE PER SECOND OUTPUT	11
B.4 SPURIOUS AND HARMONIC CONTENT	11
B.5 PHASE NOISE MEASUREMENTS	12
B.6 FREQUENCY ACCURACY	12
B.7 FREQUENCY STABILITY	12
Appendix C	13
DESCRIPTION OF TEST RESULTS	13
C.1 TEST DESCRIPTION	13
C.1.1 Position	13
C.1.2 Time Accuracy	14
C.1.3 One Pulse Per Second Characterization	14
C.1.4 Spurious And Harmonic Content	14
C.1.5 Phase Noise Measurements	14
C.1.6 Frequency Accuracy	15
C.1.7 Fractional Frequency Stability	15
C.1.8 Conclusions	15
REFERENCES	23

DIAGRAMS

Diagram A.1. TIME CALIBRATION	7
Diagram A.2. Precision clock evaluation facility.	9

TABLES

Table 1. Matrix of Test Objectives	2
Table 2. TGR Position Error Measurements	4
Table 3. TGR receiver specification and error in the keyed mode.	4
Table 4. Characteristics of the 1PPS	5
Table 5. Spurious And Harmonic Content	5
Table 6. Phase Noise	5
Table 7. Frequency Accuracy	6
Table 8. Allan Deviation	6
Table 7. Position Measurements	13
Table 8. Frequency Accuracy	15

GRAPHS

Figure C.1. TGR receiver time error VS USNO(MC2). Internal delay set to zero.	16
Figure C.2. 1PPS output.	16
Figure C.3. Rise time of 1PPS.	17
Figure C.4. Fall time of 1PPS.	17
Figure C.5. 5MHz output spectrum to 50 MHz with no $1/4\lambda$ trap at 5 MHz.	18
Figure C.6. 5MHz output spectrum to 50 MHz with a $1/4\lambda$ trap at 5 MHz.	18
Figure C.7. Output spectrum of 5 MHz output with a $1/4\lambda$ trap at 5 MHz.	19
Figure C.8. Phase noise to 10 Hz from the 5 MHz output.	19
Figure C.9. Phase noise to 100 Hz from the 5 MHz output.	20
Figure C.10. Phase noise to 2 KHz from the 5 MHz output.	20
Figure C.11. Phase noise to 10 kHz from the 5 MHz output.	21
Figure C.12. Phase noise to 100 KHz form the 5 MHz output.	21
Figure C.13. Frequency offset data of the receiver's 5 MHz output.	22
Figure C.14. Allan Deviation plot of the frequency data and specifications.	22

EXECUTIVE SUMMARY

The Global Positioning System (GPS) Joint Program Offices (JPO), Los Angeles Air Force Base, California, has established a Center of Expertise (COE) comprised of several agencies each providing unique GPS receiver test capabilities. The Responsible Test Organization (RTO) for the COE is the 746th Test Group, 46th Guidance Test Squadron, Holloman Air Force Base, New Mexico. The Naval Research Laboratory (NRL) has been designated as the Participating Test Organization (PTO) with the responsibility of testing the Precise Time and Time Interval (PTTI) characteristics of both commercial and military GPS receivers¹.

The Defense Information System Agency (DISA) operates several hundred communication sites throughout the world. These sites have a requirement for precision frequency standards. Loran-C frequency receivers have been used successfully for many years at these DISA communication sites. With the advent of GPS the U.S. Coast Guard discontinued its worldwide management of the Loran system. In 1992 the GPS JPO, acting as the Lead Military Department for procurement of the DISA receiver, selected Quantic Industries to deliver Precise Position Service (PPS) C/A code Timing GPS Receivers (TGR) to be used to replace the DISA Loran-C receivers. A TGR receiver was delivered to NRL in December of 1993 and initial testing began. Lengthy technical difficulties delayed the completion of the testing until July of 1996.

The TGR tested at NRL was found to meet most of the time and frequency performance specifications. The TGR failed the frequency stability specification between 10 and 600 seconds due to poor temperature control of the crystal oscillator. During long term testing it was found that the TGR does not make the required GPS to UTC(USNO) time corrections as specified in GPS ICD-200. Once the receiver was calibrated for internal time delay it would give GPS time to within \pm 11.6 nanoseconds.

However the TGR's failure to make the requisite time corrections was found to be due to the TGR never reading and interpreting each SV's broadcast ephemeris. The TGR's internal clock is always slaved to the initially read SV's broadcast ephemeris. The TGR's internal clock is always slaved to the initially read SV broadcast ephemeris, thereby inducing a continuous drift in time. Each TGR will thus drift at its own rate. The only known methodology for correcting this phenomena is to remove all electrical power, reapply power, and reacquire a new constellation. Again, over time, the TGR will drift and diverge from GPS time.

QUANTIC GLOBAL POSITIONING SYSTEM TIMING RECEIVER LIVE STATIC TEST.

1. INTRODUCTION

The Global Positioning System (GPS) Joint Program Offices (JPO), Los Angeles Air Force Base, California, has established a Center of Expertise (COE) comprised of several agencies each providing unique GPS receiver test capabilities. The Responsible Test Organization (RTO) for the COE is the 746th Test Group, 46th Guidance Test Squadron, Holloman Air Force Base, New Mexico.

The Naval Research Laboratory (NRL) has been designated as the Participating Test Organization (PTO) with the responsibility of testing the Precise Time and Time Interval (PTTI) characteristics and accuracy of both commercial and military GPS receivers. NRL has a precision clock evaluation facility (PCEF) with time and frequency traceable to the U.S. Naval Observatory (USNO) Universal Time Coordinated (UTC). The test procedures used by NRL are taken from the COE's CORE Inertial Navigation System/GPS Receiver/Embedded GPS-INS (INS/GR/EGI) Test Plan¹ and from NRL's internal test plan² prepared as a COE member.

The Defense Information System Agency (DISA) operates several hundred communication sites throughout the world. These sites have a requirement for precision frequency standards. Loran-C frequency receivers have been used successfully for many years at these DISA communication sites. With the advent of GPS, the U.S. Coast Guard discontinued its worldwide management of the Loran system. In 1992 the GPS JPO, acting as the Lead Military Department for procurement of the DISA receiver, selected Quantic Industries to deliver Precise Position Service (PPS) C/A code Timing GPS Receivers (TGR) to be used to replace the DISA Loran-C receivers. These receivers were originally scheduled to be delivered during the summer of 1993. In September 1994, because of the lengthy technical delays, DISA decided it could no longer wait for the Quantic GPS receivers. They purchased and fielded 270 GPS receivers from Truetime, Inc. instead. A TGR receiver was delivered to NRL in December of 1993 and initial testing began. Lengthy technical difficulties with the receiver delayed the completion of the testing until July of 1996.

1.1 Test Item Description

The TGR is a GPS timing receiver designed to provide precise time and frequency that is traceable to USNO to within 100 nanoseconds (ns), and the TGR uses the L1 (1575.42

Manuscript approved 8 August 1997

Megahertz) Coarse Acquisition (C/A) code signal only. The TGR provides precise positioning service (PPS) by removing the effects of selective availability (SA) by incorporating a PPS security module (PPS-SM) loaded with an authorized security key to remove SA. The TGR has been designed to automatically obtain satellite signal acquisition, compute the position of its antenna, and make all necessary corrections to the signal to obtain accurate position and timing information. The receiver achieves a position accuracy of less than 10 meters.

When the position and time has been established, the TGR can measure the offset (difference) between external 1 PPS time, or 1 or 5 MHz frequency inputs and GPS disciplined values.

The receiver set, Model Q-5200/SM, consist of an antenna, AS-4345/GSQ-215, and timing GPS receiver R-2554/GSQ-215. The antenna contains an amplifier and down converts the L1 signal to 152.828 MHz IF frequency. The receiver set becomes part of the AN/GSQ-215 frequency control set which is a rack containing other timing equipment. The receiver under test is serial number (SN) 3.

2. TEST OBJECTIVES

Evaluate the frequency and timing performance of TGR, Model R-2554/GSQ-215 receiver with respect to the vendor and TGR specifications. The specific test objectives are summarized below.

2.1 Performance Evaluation, Specifications, Test, And Document Paragraph Matrix

Table 1 provides a matrix of the paragraph numbers where the TGR performance specification, test description, and test results can be found. A comparison of the TGR performance specifications and the performance specifications to the TGR test results are made in the test result paragraphs.

Test Objective: Evaluate	TGR Performance Specification Paragraph	TGR Test Description Paragraph	TGR Test Result Paragraph
Self Survey Accuracy	B.1	3.1	4.1
Timing Accuracy	B.2	3.2	4.2
One Pulse-Per-Sec Output	B.3	3.3	4.3
Spurious And Harmonic Content	B.4	3.4	4.4
Phase Noise Measurements	B.5	3.5	4.5
Frequency Accuracy	B.6	3.6	4.6
Frequency Stability	B.7	3.7	4.7

Table 1. Matrix of Test Objectives Paragraph Numbers

3. TEST DESCRIPTIONS

All tests were performed using reception from live operational satellites. Details of measurement methods and test equipment used are presented in Appendix A. Testing started during the summer of 1994 and was concluded in Jan 1996.

3.1 Position

The receiver's GPS antenna was placed on building 35 which is near NRL's Defense Mapping Agency (DMA) benchmark on the roof of NRL building 53.

3.2 Time Accuracy

The TGR One Pulse Per Second (1PPS) timing output was measured against the NRL time scale. This time scale is traceable to USNO (UTC) to within a few nanoseconds.

3.3 1PPS Output

Pulse width, rise and fall times, peak voltage, and overall wave form of the 1PPS were displayed on a Giga-sample digital sampling storage oscilloscope and recorded.

3.4 Spurious And Harmonic Content

The 5 MHz sine wave output on the rear panel was checked for spurious and harmonic signals.

3.5 Phase Noise Measurements

The 5 MHz sine wave output on the rear panel was examined for phase noise and spurious content from DC to 100 KHz.

3.6 Frequency Accuracy

The absolute frequency offset of the 5 MHz sine wave output with respect to the NRL house frequency reference Hydrogen Maser was measured. The NRL maser frequency is then referenced to the USNO Master Clock.

3.7 Fractional Frequency Stability

Phase difference data between the NRL N1 Maser and the TGR 5 MHz sine wave output were recorded. This data was then used to calculate the frequency stability of the TGR in the form of the Allan Deviation.

4. TEST RESULTS

A brief synopsis of the results of the tests is presented in the following paragraphs. Detailed descriptions of the results as well as graphs of wave forms and measurements are provided in Appendix C.

4.1 Position

The Truetime TGR GPS antenna was installed on the roof of NRL building 35, at a known distance from the Defense Mapping Agency (DMA) benchmark on building 53. Position coordinate errors are listed in table 2, and the RSS position accuracy and specification shown in table 3.

Dimension	Receiver derived position WGS-84	Receiver true position WGS-84	Error
height	-20 m	-20.15 m	-.153 m
latitude	N 38° 49' 14.23"	N 38° 49' 14.10"	N 4.01 m
longitude	W 77° 01' 28.73"	W 77° 01' 28.81"	W 1.92 m

Table 2. TGR Position Error Measurements

Receiver	Spherical Error, RSS	Specification
TGR	4.45 m typical	< 5 m

Table 3. TGR receiver specification and error in the keyed mode.

4.2 Timing Accuracy

A detailed calibration of all TGR timing system errors were completed. The TGR 1PPS time signal, when averaged over 25 days was found to be lagging GPS time by 202 ± 10 nanoseconds (ns) as determined by the NRL measurement system. This error remains constant during the measurement time. The instantaneous measurement of time by the receiver is a fluctuating value because of receiver noise and has a one sigma value of ± 11.6 ns. For the measurement, the receiver's internal time delay was set to zero and 202 nanoseconds would be the delay time that would be put into the receiver to remove the time offset. The TGR does not make the of GPS to UTC(USNO) corrections as specified in GPS ICD-200. It appears to make the GPS to UTC(USNO) correction and ionosphere correction when first turned on but fails to update this correction at any later time. This means that the time accuracy of the TGR with respect to UTC(USNO) will degrade over long periods of continuous operation due to misapplication of the outdated correction. Used in the GPS time mode, the TGR will preform well but will not correct for any bias between GPS time and UTC(USNO). There will also be daily cycles in the time output due to having an inaccurate ionospheric correction.

4.3 One Pulse-Per-Second Output

The output 1PPS is a positive-going, 20 microsecond wide pulse when driving a 50 ohm load impedance. Table 4 contains a summary of these measurements.

	Amplitude	Rise time	Fall Time	Pulse Width
TGR Measurement	10.4 V	< 10 ns	< 20 ns	20 us
TGR Specification	10 V \pm 10 %	< 20 ns	< 1 us	20 us \pm 5%

Table 4. Characteristics of the 1PPS

4.4 Spurious And Harmonic Content

The TGR primary frequency outputs have a signal level of + 13 dBm. Numerous unwanted frequency spurs are present, but all are within specification except the spurs at 1 and 3 MHz. The summary of the test results are shown in table 5.

5 MHz Output	Spurious	Spurious	Harmonic @ 10 MHz
TGR Specification	-60 dBc @ 1 MHz	-60 dBc @ 3 MHz	-40 dBc
TGR Measured	-59.3 dBc @ 1 MHz	-55 dBc @ 3 MHz	-70.9 dBc

Table 5. Spurious And Harmonic Content

4.5 Phase Noise Measurements

The 5 MHz sine wave output on the rear panel was examined for phase noise and spurious content. The TGR receiver has a phase noise floor at -153 dBc/Hz with a number of spurs that rise above it. Although the spurs rise above the TGR specification lines, it is the phase noise floor that is being specified. General results are stated in table 6.

Frequency	10 Hz	100 Hz	1 KHz	100 KHz
TGR Specification	-87 dBc/Hz	-120 dBc/Hz	-135 dBc/Hz	None
TGR Measured	-125 dBc/Hz	-135 dBc/Hz	-144 dBc/Hz	-153 dBc/Hz

Table 6. Phase Noise

4.6 Frequency Accuracy

The absolute frequency offset of the 5 MHz sine wave output with respect to USNO was measured. The data is shown in figure C.13 with the results shown in table 7. The TGR frequency measurement value is to be the result of data averaged from ten 3 hour averaging periods per the TGR SCN-3 specifications. However the average fractional frequency offset or accuracy was several orders of magnitude better than the specification so that the average value of computed and presented in table 7.

	Specifications	Measured
TGR	2×10^{-12}	1.02^{-15}

Table 7. Frequency Accuracy

4.7 Fractional Frequency Stability

Phase data was taken from the 5 MHz sine wave output at one second intervals for one hour and at one hour intervals over 10 days. These two data sets were used to calculate the Allan Deviation for sample periods of between 1 and 300,000 seconds with the results given in table 8. The TGR did not meet the TGR frequency stability specifications at 100 seconds.

Sample Interval, Seconds	1	10	100	1,000	10,000	Day
TGR Specification	1×10^{-10}	None	1.5×10^{-11}	1.0×10^{-11}	7.0×10^{-12}	None
TGR Measured	2.5×10^{-11}	2×10^{-11}	2.2×10^{-11}	7.5×10^{-12}	1×10^{-12}	2×10^{-13}

Table 8. Allan Deviation (Bold type indicates out of spec.)

4.8 Conclusions

The TGR tested at NRL was found to meet most of the time and frequency performance specifications. The TGR failed the frequency stability specification between 10 and 600 seconds and is believed to be due to lack of temperature control of the crystal oscillator. The electronic servo which slaves the oscillator to GPS has to have a short time constant to correct the oscillator frequency but the short time constant allows more of the noise in the GPS measurements to affect the output. During long term testing it was found that the TGR does not make the required GPS to UTC(USNO) time corrections as specified in GPS ICD-200. Once the receiver was calibrated for internal time delay it would give GPS time to within ± 11.6 nanoseconds for as long as the ionospheric corrections were valid. The TGR phase noise floor met all specifications whereas the it did not meet the spurious content specifications.

While still not meeting all of the specifications the TGR make a good temporary replacement for the Loran-C receivers. The TGR time accuracy comes from the fact that it is a C/A-code receiver with a Precise Positioning System Security Module (PPS-SM) permitting operation with a signal that has as Selective Availability effects removed.

Appendix A

MEASUREMENT METHODS

A.1 TIME CALIBRATION

The time and frequency references used at the NRL Precise Clock Evaluation Facility (PCEF) are two Sigma Tau hydrogen masers. These masers produce both one pulse per second (1PPS) and a 5 MHz sine wave frequency reference signals that are synchronous with UTC(USNO). The traceable characterization of the reference 1PPS is accomplished using a "traveling clock" procedure augmented by continuous phase monitoring at NRL. First a measurement is made of the time epoch between NRL's Maser and a mobile HP-5071 Cesium Frequency Standard "traveling clock". Then this Cesium is transported to USNO and compared with their Master Clock and then returned to NRL again for a final comparison called clock closure. This procedure produces two difference equations. Simultaneous solution of these difference equations removes the "traveling clock" and produces the time difference between the NRL's Maser and the USNO's Master Clock.

To monitor the accumulated phase difference during periods between traveling clock trips, a continuous phase monitoring system is employed³ (see diagram A.1). This system uses "common viewing" of a local television station (WTTG-TV5) carrier frequency. Both USNO and NRL monitor its signal with closure over a phone link. At each site the television carrier signal is mixed with a frequency derived from the in local primary frequency standard. The difference frequency at each location is a 2250 Hz beat tone. The USNO beat tone is transferred to NRL via a dedicated phone line. At NRL, this beat tone is compared with a similarly derived beat tone to produce the phase difference between the USNO Master Clock and NRL's Maser. Combined with the traveling clock data, an estimate of the absolute time error between each location is maintained to less than two nanoseconds.

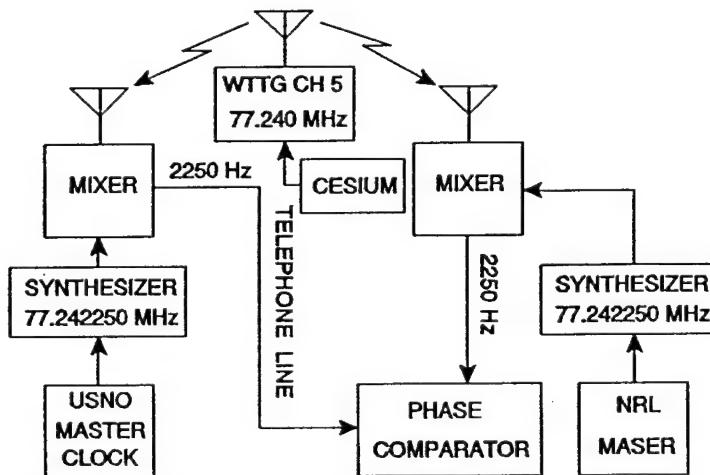


Diagram A.1. TIME CALIBRATION

A.2 ANALYSIS AND MEASUREMENTS

The Truetime's 1PPS was connected to the NRL 1PPS measurement system. This measurement system is capable of measuring sixteen input channels sequentially with 20 picoseconds single shot resolution at a sample interval of five minutes.

The receiver's 5 MHz output was connected to NRL's short and long term phase measurement systems, see figure A.2. The short term system is capable of measuring 12 inputs simultaneously, using dual mixer techniques, at a τ -interval of 20 seconds. It has a system noise floor of 6×10^{-12} over τ . The long term system is capable of measuring 48 inputs simultaneously. It too, uses dual mixer techniques, at a τ -interval of one hour. It has a system noise floor of 6×10^{-12} over τ . These systems together provided intermediate and long term fractional frequency data.

A.3 LIST OF TEST EQUIPMENT

The receiver's RF output was tested for phase noise and spurious signals using an extremely low noise test suite of equipment. Consisting of an HP 3562 Dynamic Signal Analyzer, a FemtoSeconds FSS 1000, and an HP 10 MHz crystal, the system measured the single sideband phase noise, $\mathcal{L}(f)$, from DC to 100 kHz. Spurious response was documented using an HP 8563 Spectrum Analyzer. All these systems taken together provided the necessary information about the receiver's precision time and frequency outputs. A complete list of the equipment used is shown below. A block diagram of the measurement system and how it connects to the TGR is shown in Diagram A.2.

IBM-AT 486 Computer used for serial data collection (Not shown)
FemtoSeconds Phase noise Detector FSS 1000
Hewlett Packard 10 MHz Quartz Oscillator
Hewlett Packard 3562 Dynamic Fast Fourier Transform Signal Analyzer (FFT)
Hewlett Packard 8753 Network Analyzer (Not Shown, Used To Measure Cable Delays)
Hewlett Packard Digital Oscilloscope 54111D
Hewlett Packard Spectrum Analyzer 8563A
Hewlett Packard Digital Synthesizer 3325
Time System Technology (TST), Inc. 6460 Clock
Sigma Tau Maser

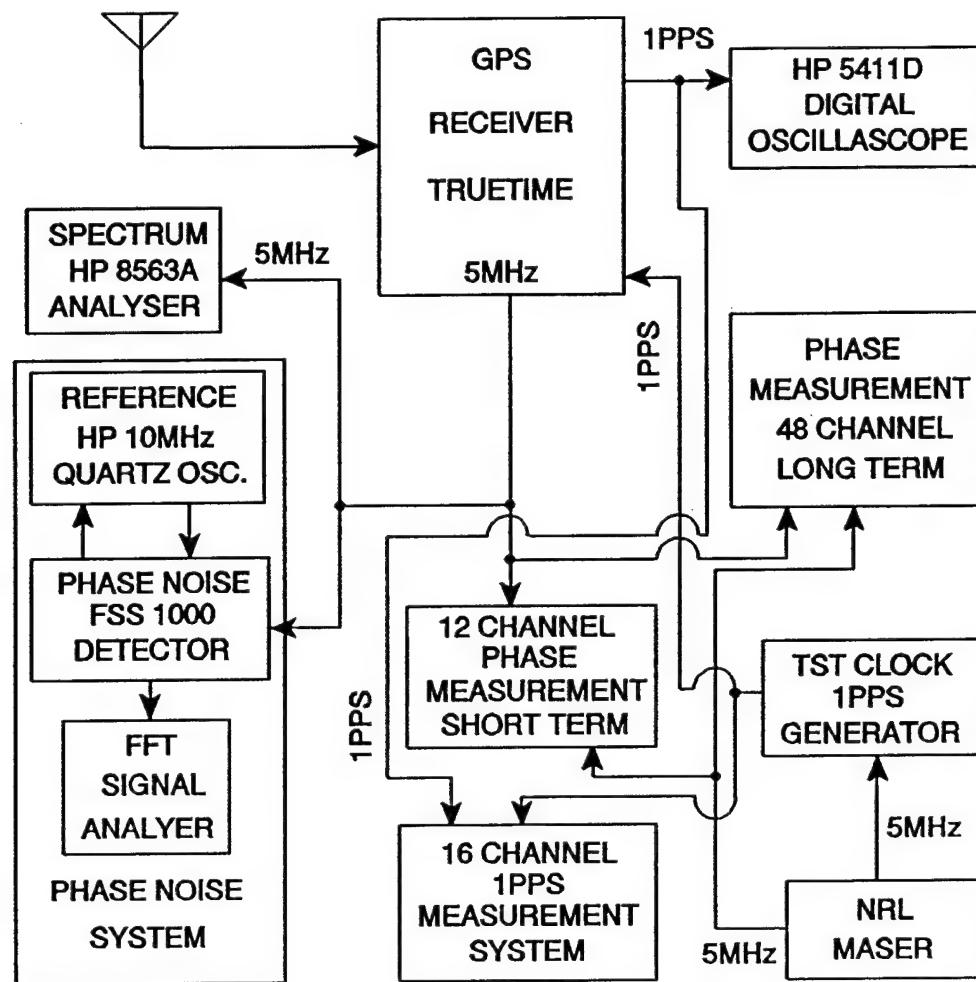


Diagram A.2. Precision clock evaluation facility.

This page intentionally left blank.

Appendix B

TGR SPECIFICATIONS (SCN-3)

The TGR specifications⁴ are copied directly from the manual along with their section number as listed in the manual.

B.1 SELF SURVEY ACCURACY

3.2.1.1.5.2 Position Determination

The TGR shall be capable of determining the position of its antenna phase center in the World Geodetic System - 1984 (WGS-84) datum. Following operator command, or automatically, position determination shall be accomplished without requiring operator action. The TGR shall meet the frequency and time requirements when the position is determined by the TGR set or when a position is entered manually from a surveyed position accurate to within a 5 meters or less radial error. Manual entry of position data shall be entered as altitude, latitude and longitude and shall override any previous position computed or entered.

B.2 TIMING ACCURACY

3.2.1.1.1 1PPS Transfer Accuracy

Transfer accuracy relative to UTC (or GPS, if selected) Time shall be less than 100 ns RMS whenever one or more satellites are being tracked and the TGR antenna is positioned as described in paragraph 3.2.1.1.4.

B.3 ONE PULSE PER SECOND OUTPUT

3.2.2.1.2.2.2 Pulse Width

Pulse width shall be 20 microseconds \pm 5 percent. The rise time shall be less than 20 nanoseconds and the fall time shall be less than one microsecond, as illustrated in MIL-STD-188-115

3.2.2.1.2.2.1 Output Voltage

The pulse amplitude shall be between 10 volts \pm 10 percent and 0 volts \pm 1 volt, as illustrated in MIL-STD-188-115.

B.4 SPURIOUS AND HARMONIC CONTENT

3.2.2.1. Time, Frequency, and Control Inputs and Outputs

a. Harmonic Distortion

As specified in MIL-STD-188-155, The harmonic distortion for the sine wave signal shall be at least 40 dB below the rated output level. The level of any signal

component not a harmonic of the signal frequency shall be at least 60 dB below the rated output level.

B.5 PHASE NOISE MEASUREMENTS

3.2.2.1 Time, Frequency, and control Inputs and Outputs

b. Phase Noise

The following specification shall be met at all times after a 1 hour warm up period:

- > - 87 dB @ 10 Hz from carrier
- > - 120 dB @ 100 Hz from carrier
- > - 135 dB @ 1 KHz from carrier

B.6 FREQUENCY ACCURACY

3.2.1.2 Frequency Accuracy

When the TGR is operating with outputs disciplined to GPS and is tracking satellites, the frequency accuracy shall be better than 1.0×10^{-11} RMS, when computed from a set of 9 frequency measurements, each measurement being averaged over one of 9 consecutive 10,000 second intervals.

B.7 FREQUENCY STABILITY

3.2.1.3 Frequency Stability

The frequency stability shall meet or exceed the following specifications:

1 sec (Allan var.) avg:	1.0×10^{-10}
100 sec (Allan var.) avg:	1.5×10^{-11}
1000 sec (Allan var.) avg:	1.0×10^{-11}
10,000 sec (Allan var.) avg:	7.0×10^{-12} **
Frequency drift/day:	5.0×10^{-10} (after loss of GPS tracking)

* * minimum of 10 pairs, non overlapping

Appendix C

DESCRIPTION OF TEST RESULTS

C.1 TEST DESCRIPTION

All measurements were performed with the receiver in the keyed mode, using live satellites.

C.1.1 Position

The Truetime TGR GPS antenna was installed on the roof of NRL building 35, at a known distance from the Defense Mapping Agency (DMA) benchmark, calibrated in World Geodetic Survey, 1984 (WGS-84) on building 53. Position coordinate errors are listed in table 2, and the RSS position accuracy and specification shown in table C.1.

Dimension	Receiver derived position WGS-84	Receiver true position WGS-84	Error
height	-20 m	-20.15 m	-.153 m
latitude	N 38° 49' 14.23"	N 38° 49' 14.10"	N 4.01 m
longitude	W 77° 01' 28.73"	W 77° 01' 28.81"	W 1.92 m
Error RSS			4.45 m

Table 7. Position Measurements

The antenna module is a sealed unit containing an antenna-radome and a preamplifier/down-converter. The antenna module receives the 1575.42 MHz satellite L1 frequency, which is then amplified and down-converted to a IF frequency of 152.828 MHz which is sent down to the receiver. The receiver was turned on and allowed to warm up for 12 hours in the keyed mode. The approximate longitude and latitude of the receiver's antenna was loaded into the receiver, and the receiver was then allowed to self-survey the antenna location for 24 hours. Position coordinate errors are listed in table C.1. To establish an upper bound on timing errors due to position uncertainty, the Root-Squares-Summed (RSS) was computed to be 4.45 meters. The nominal timing error due to these position errors would be about 15 nanoseconds (ns).

C.1.2 Time Accuracy

A detailed calibration of all TGR timing system errors were completed. The TGR 1PPS time signal, when averaged over 25 days was found to be lagging GPS time by 202 ± 10 nanoseconds (ns) as determined by the NRL measurement system. This error remains constant during the measurement time and this data is shown in figure D.1. The instantaneous measurement of time by the receiver is a fluctuating value because of receiver noise and has a one sigma value of ± 11.6 ns. For the measurement, the receiver's internal time delay was set to zero and 202 nanoseconds would be the delay time that would be put into the receiver to remove the time offset. The GPS scale is steered⁵, as needed, on a daily basis to be within one microsecond of UTC(modulo one second). The TGR does not make the of GPS to UTC(USNO) corrections as specified in GPS ICD-200. It appears to make the GPS to UTC(USNO) correction and ionosphere correction when first turned on but fails to update this correction at any later time. This means that the time accuracy of the TGR with respect to UTC(USNO) can only be as good as GPS time.

C.1.3 One Pulse Per Second Characterization

The output 1PPS is a positive-going, 20 microsecond wide pulse when driving a 50 ohm load impedance. Table 4 contains a summary of these measurements. The full pulse is shown in figure C.2 with an amplitude of 10.4 volts with a slight overshoot. Figure C.3 shows that the TGR's 1PPS timing signal has a rise time of less than 10 nanosecond. The fall time is shown in figure C.4 is about 20 nanosecond.

C.1.4 Spurious And Harmonic Content

The 5 MHz RF output of the receiver was checked for spurious and harmonic signals. Figure C.5 shows the 5 MHz primary output at a level of +13.0 dBm along with its integer harmonics out to 50 MHz. The amplitude of the receiver's harmonic content is much less than required by the TGR specification as can be seen by the TGR specification line drawn on the plot. Another plot out to 50 MHz with a 1/4 wave trap at 5MHz to attenuate the 5 MHz is shown in figure C.6. This method increases the dynamic range of the analyzer and pulls small signals out of the analyzer system noise.

Figure C.7 is a plot of the frequency spectrum from 100 kHz to 4.95 MHz using a quarter-wave trapping stub to attenuate the main 5 MHz signal. The amplitude of the peaks at 1 MHz and 3 MHz are -59.3 dBc and -55.0 dBc respectively which are not below the specification value of -60dBc. Note that the plot is in dBm so that dBc is obtained by subtracting 60 dBc from 13 dBm. This results in a the specification line at -47 dBm in figure C.5. Also note the numerous frequency components approaching the fundamental.

C.1.5 Phase Noise Measurements

Figures C.8 through C.12 are made from the NRL single side band phase noise measurement system. They cover a span from 10 Hz to 100 kHz and are taken from the 5 MHz receiver output. All figures are in units of dB below carrier, dBc or $L(f)$. Figure C.8 is a measurement out to 10 Hz and is free of any unusual signals. In Figure C.9 multiples of 41.3 Hz

begin to appear and a peak at 60 Hz is clearly visible. Figure C.10 shows the phase noise and the continuation of the harmonic multiples of the 41.3 Hz and 60 Hz frequencies out to 2 kHz. Figure C.11 is a plot of the phase noise out to 10 KHz and is uneventful above 2 kHz. Figure C.12 shows the overall view of the phase noise floor to 100 kHz with a number of bright lines above 10 KHz. The floor of the phase noise spectra is less than what was specified for the TGR receiver. Any peaks appearing above the floor are not considered part of the phase noise and these peaks come under spurious and harmonic content.

C.1.6 Frequency Accuracy

The absolute frequency offset of the 5 MHz sine wave output with respect to USNO was measured. The data is shown in figure C.13 with the results shown in table 7. The TGR frequency measurement value is the result of data averaged from ten 3 hour averaging periods per the TGR SCN-3 specifications. However the average fractional frequency offset or accuracy was several orders of magnitude better than the specification so that the average value of the data in figure 13 was computed and presented in table 7.

	Specifications	Measured
TGR	2×10^{-12}	1.02^{-15}

Table 8. Frequency Accuracy

C.1.7 Fractional Frequency Stability

Phase data was taken from the 5 MHz sine wave output at one second intervals for one hour and at one hour intervals over 10 days. These two data sets were used to calculate the Allan Deviation for sample periods of between 1 and 300,000 seconds. Figure D.14 is an Allan Deviation, $\sigma_y(\tau)$, plot of the frequency data. The slight rise of the TGR's Allan Deviation above specifications between 10 and 600 seconds is due to lack of temperature control of the crystal oscillator.

C.1.8 Conclusions

The TGR tested at NRL was found to meet most of the time and frequency performance specifications. The TGR failed the frequency stability specification between 10 and 600 seconds because of lack of temperature control of the crystal oscillator. During long term testing it was found that the TGR does not make the required GPS to UTC(USNO) time corrections as specified in GPS ICD-200. Once the receiver was calibrated for internal time delay it would give GPS time to within ± 11.6 nanoseconds. The TGR phase noise floor met all specifications.

While still not meeting all of the specifications the TGR make a good temporary replacement for the Loran-C receivers. The TGR time accuracy comes from the fact that it is a PPS code capable receiver.

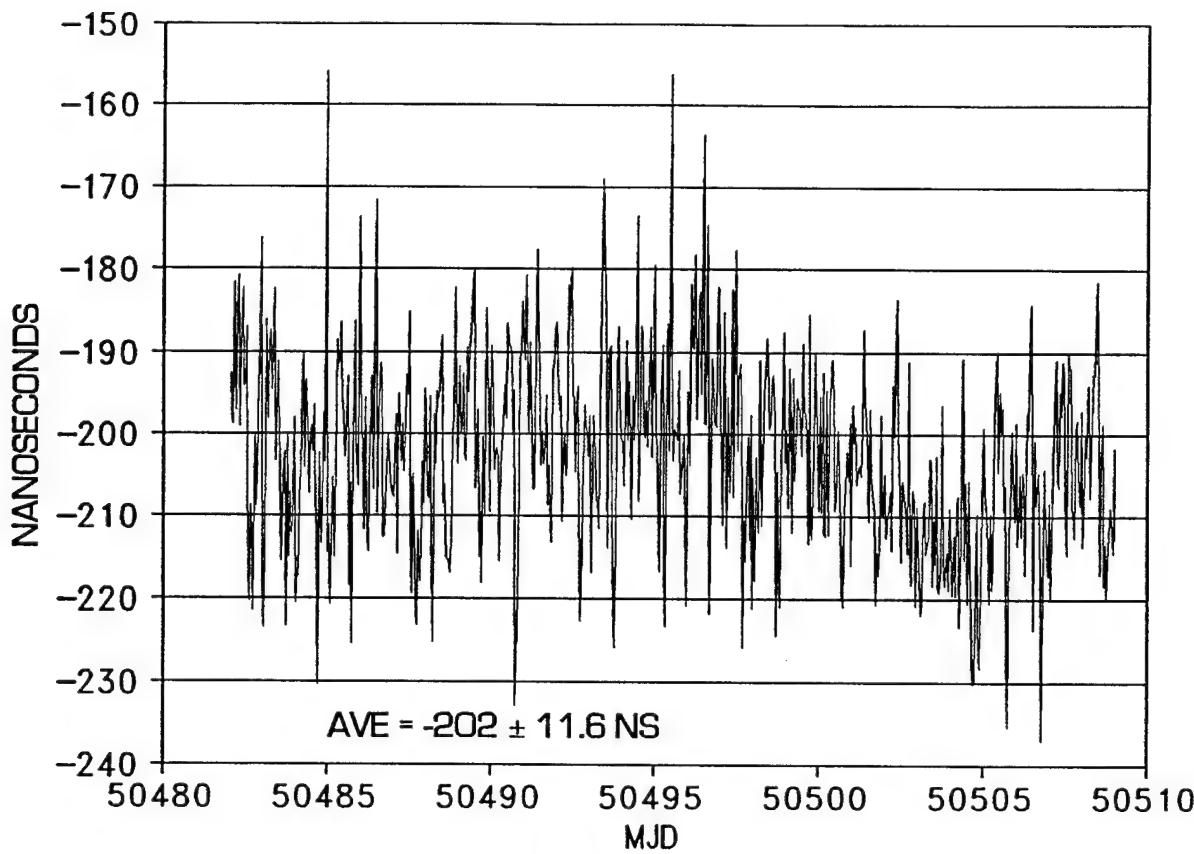


Figure C.1. TGR time error VS USNO(MC2). Internal delay set to zero.

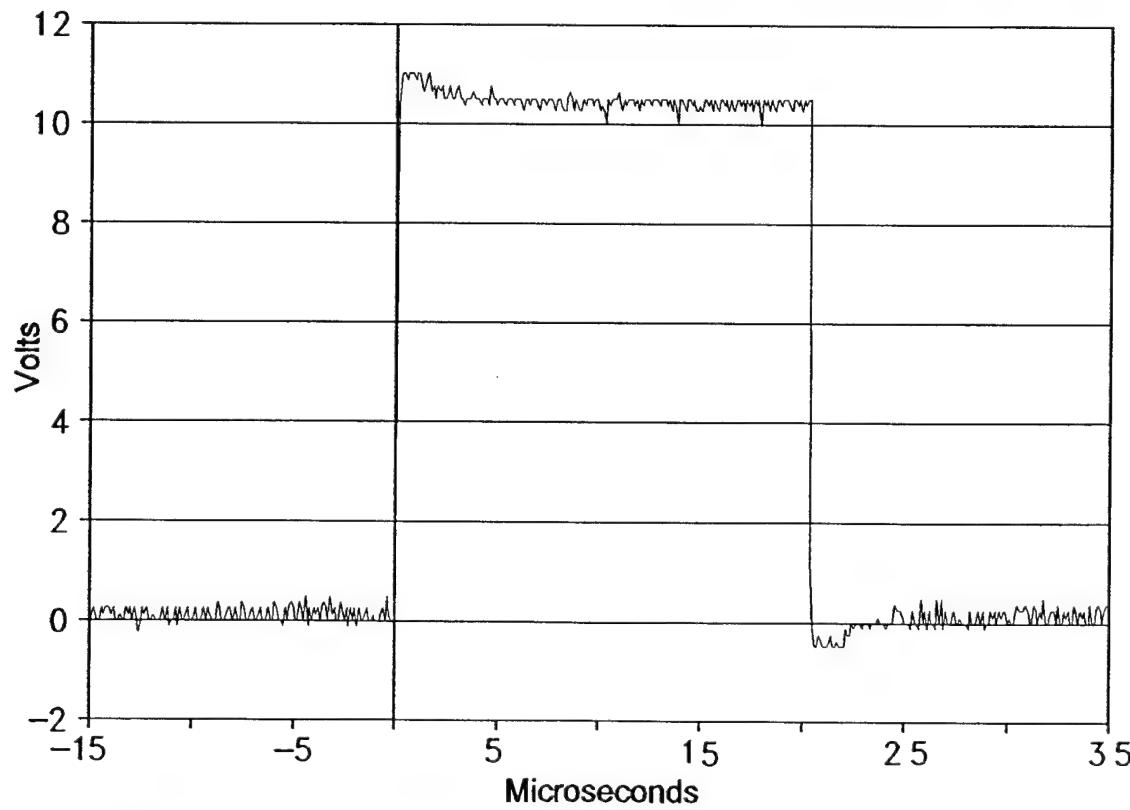


Figure C.2. 1PPS output.

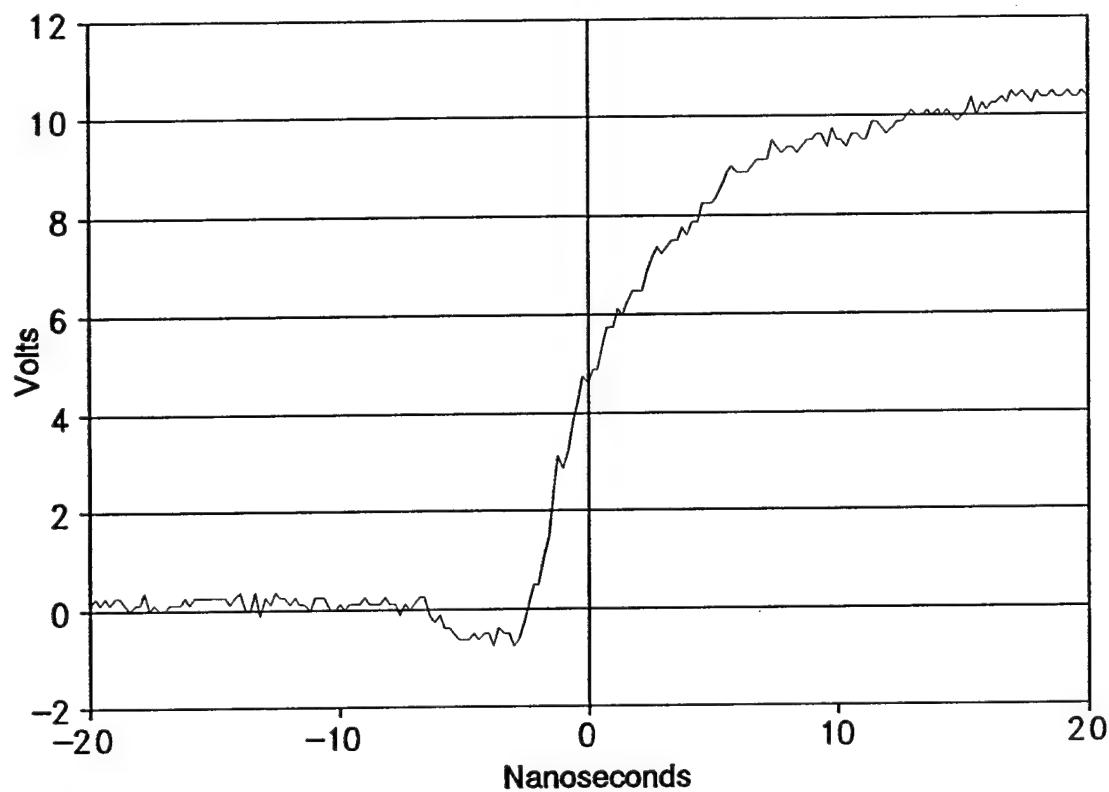


Figure C.3. Rise time of 1PPS.

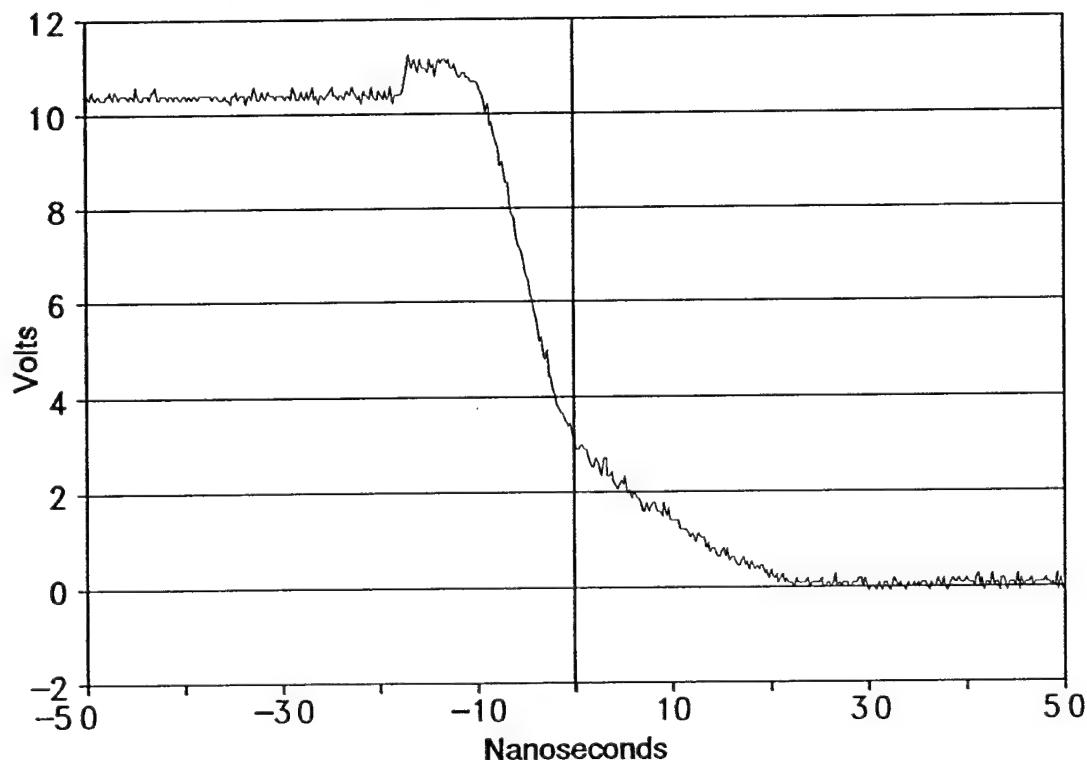


Figure C.4. Fall time of the 1PPS pulse.

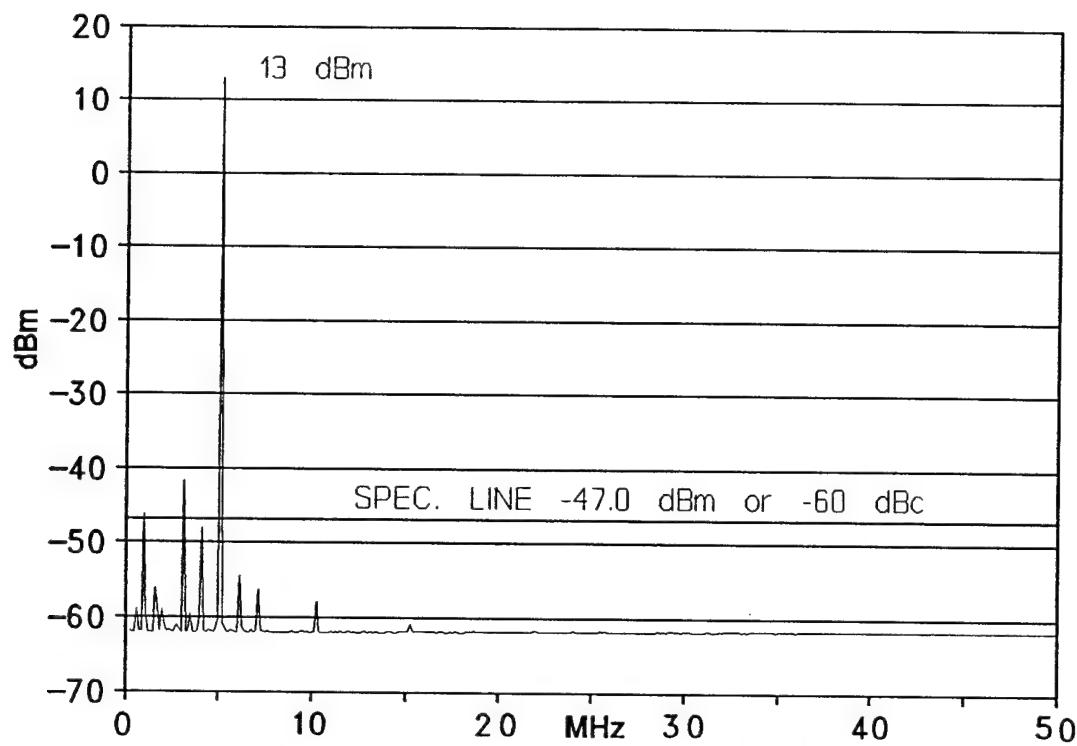


Figure C.5. 5 MHz output spectrum to 50 MHz with no $1/4\lambda$ trap at 5 MHz

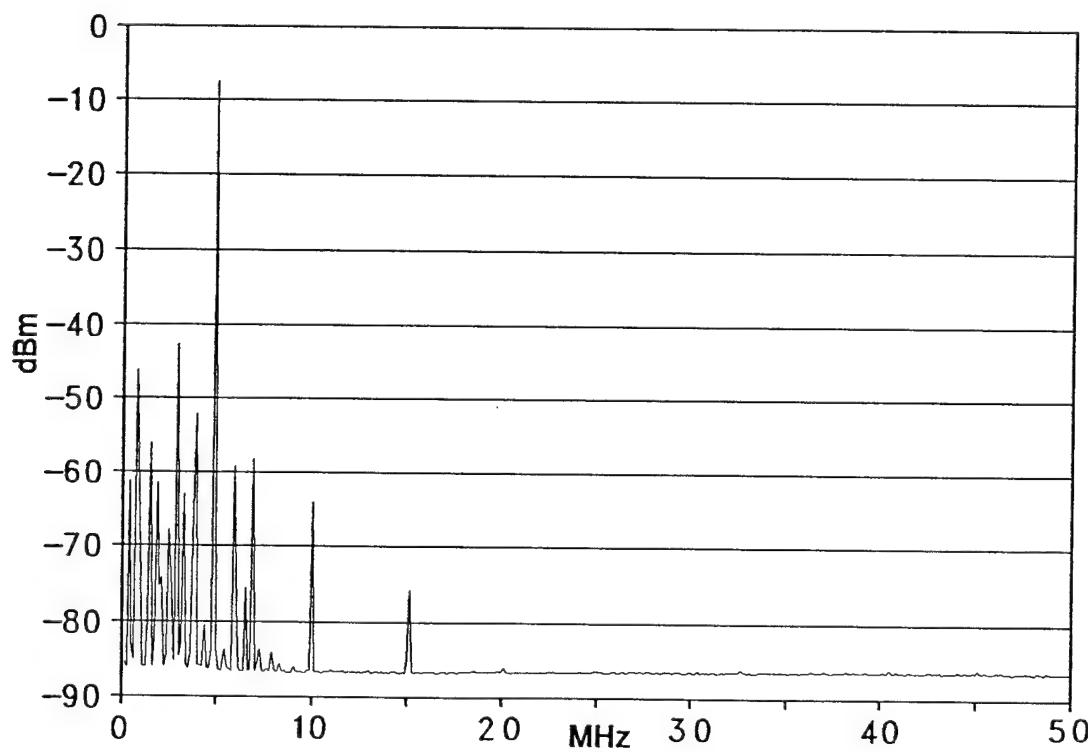


Figure C.6. 5 MHz output spectrum to 50 MHz with a $1/4\lambda$ trap at 5 MHz.

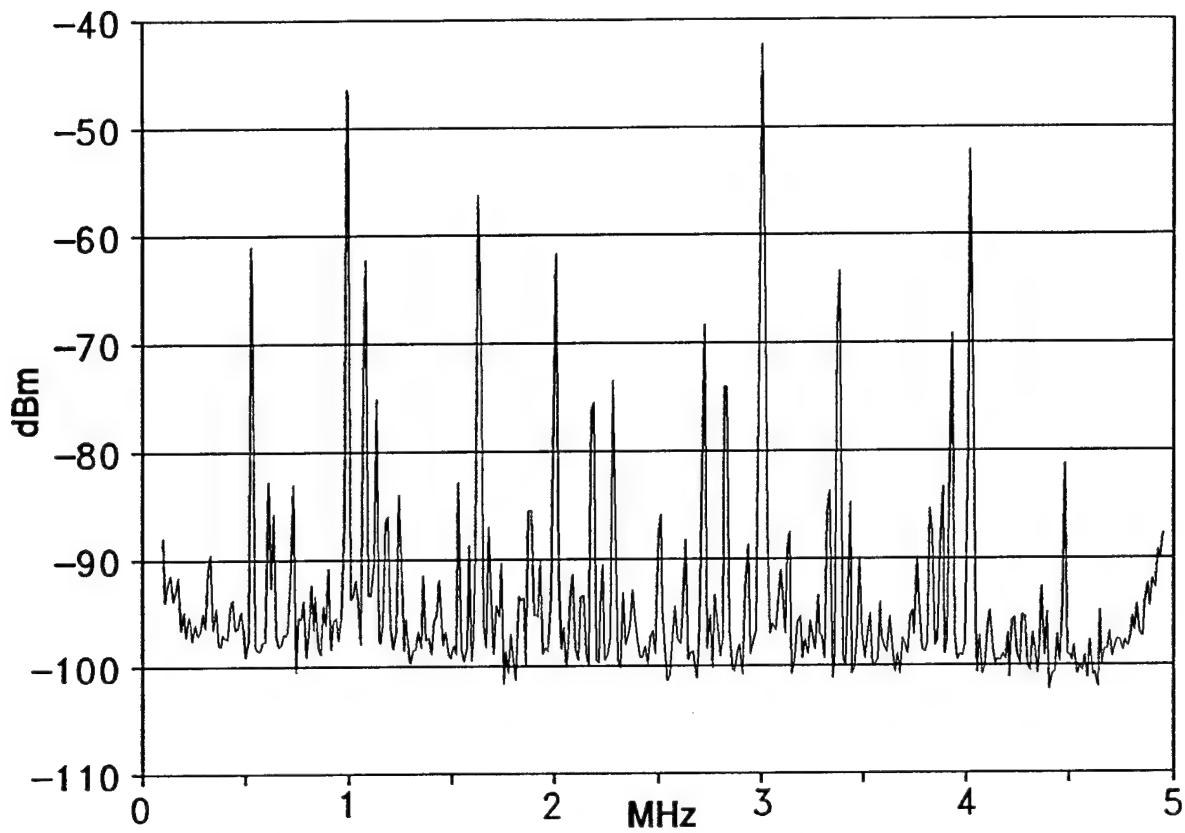


Figure C.7. Output spectrum of 5 MHz output with a $1/4\lambda$ trap at 5 MHz.

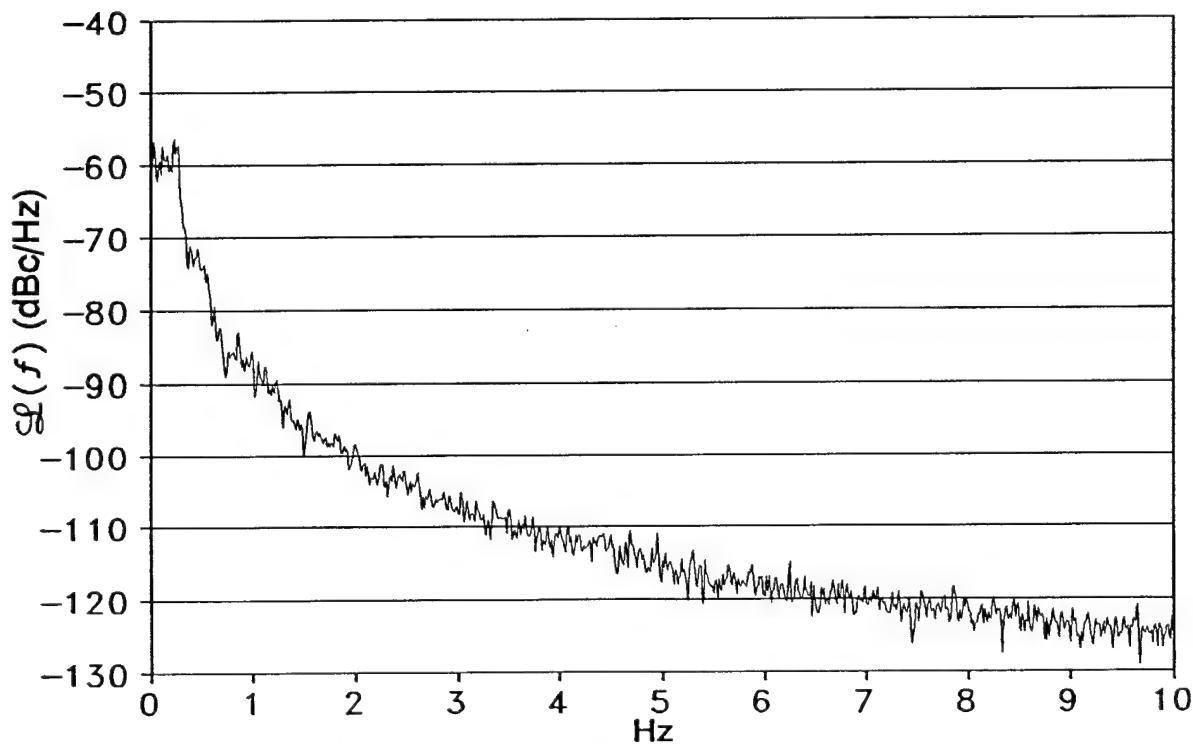


Figure C.8. Phase noise to 10 Hz from the 5 MHz output.

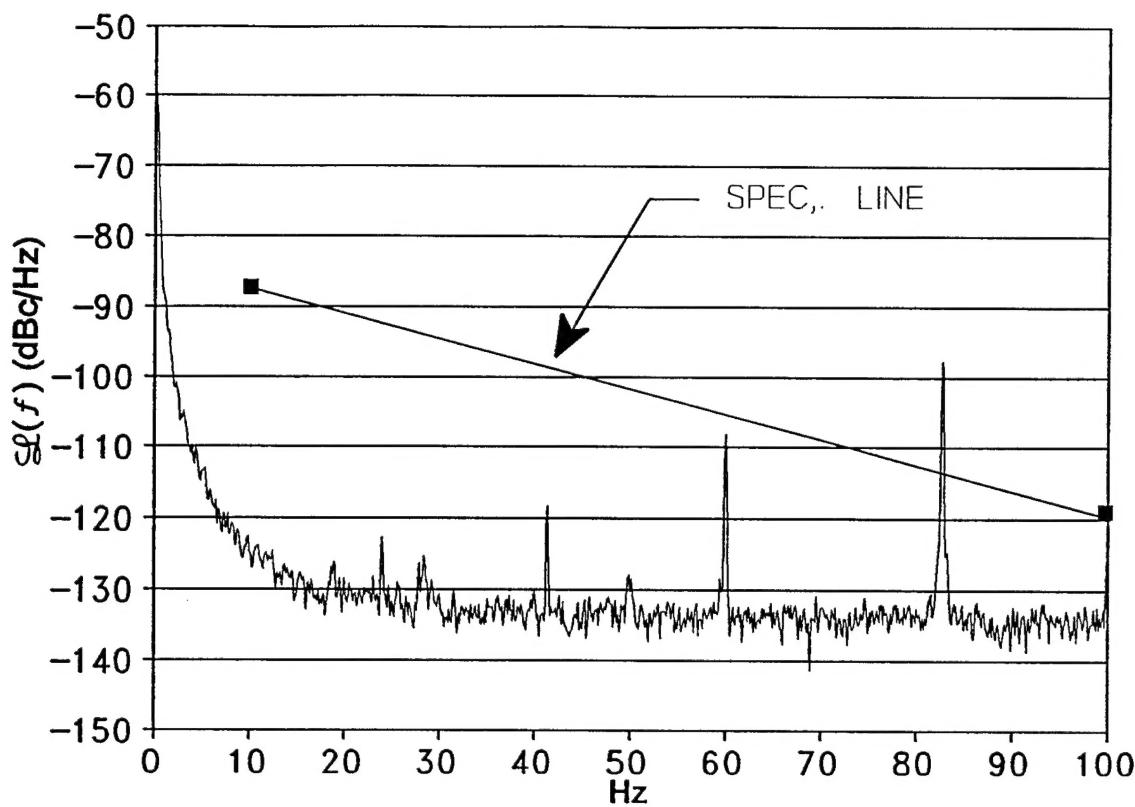


Figure C.9. Phase noise to 100 Hz from the 5 MHz output.

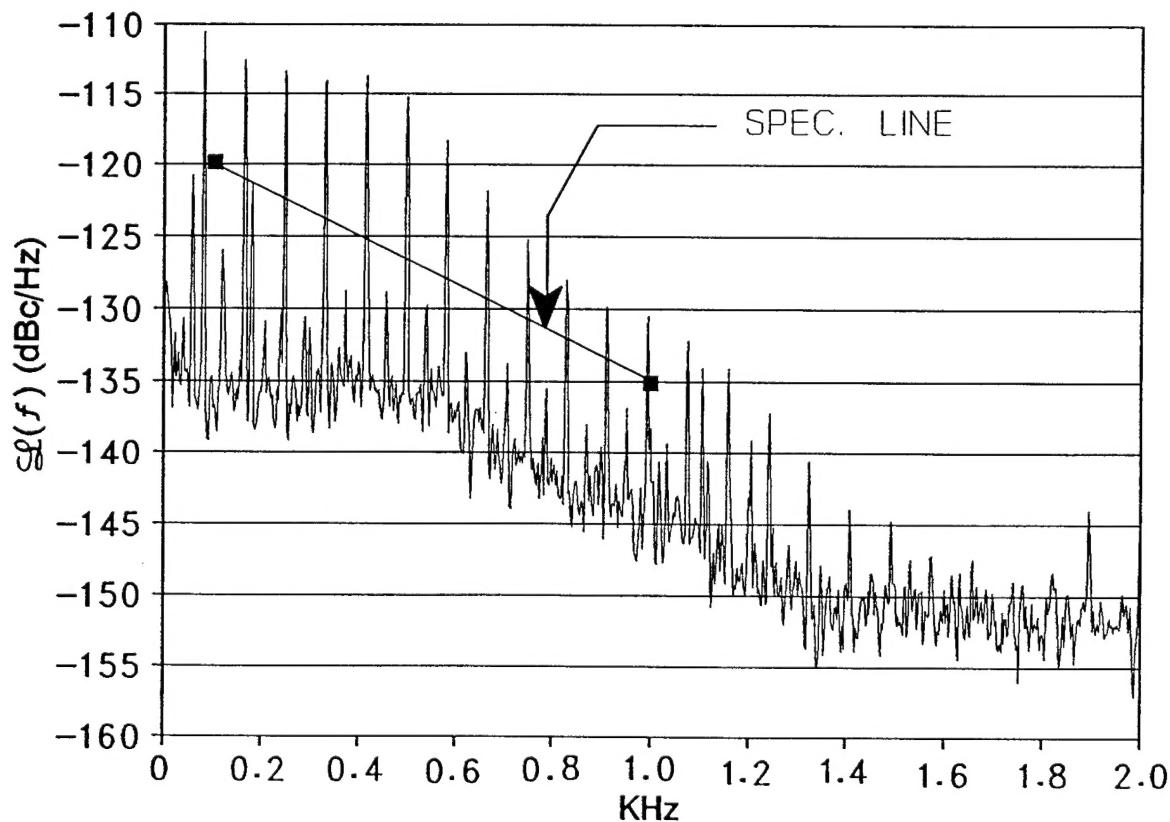


Figure C.10. Phase noise to 2 KHz from the 5 MHz output.

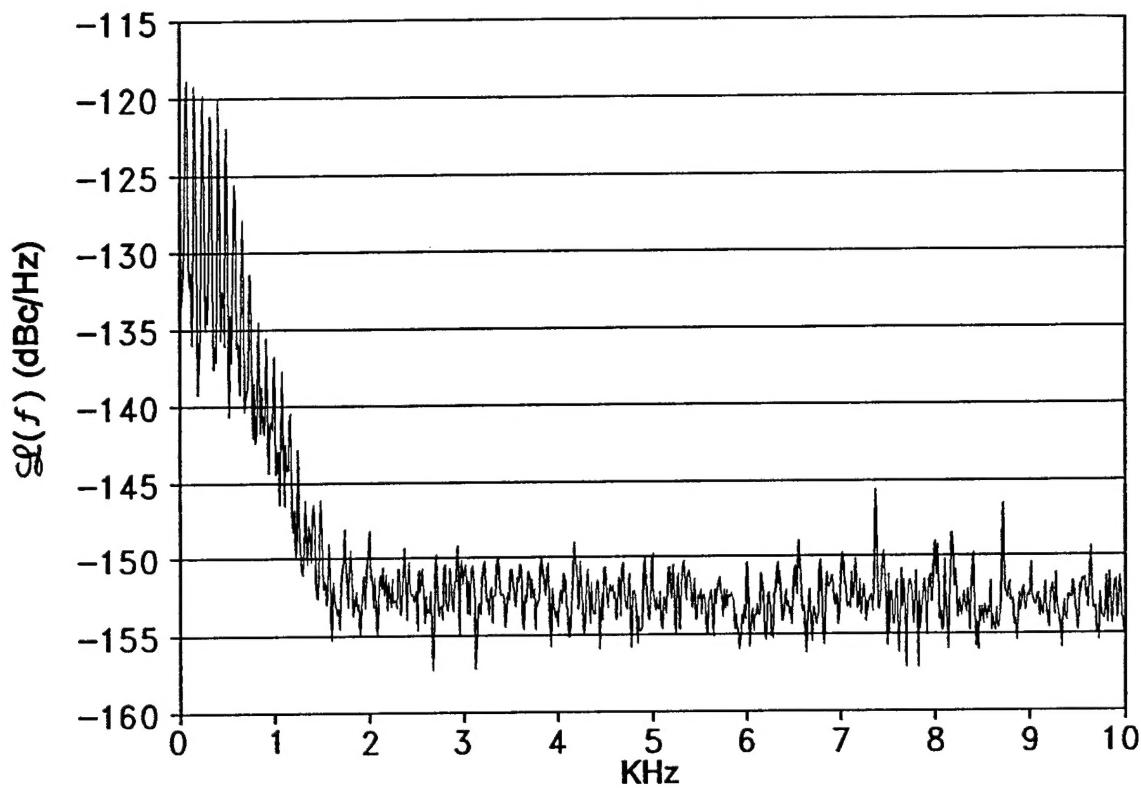


Figure C.11. Phase noise to 10 KHz from the 5 MHz output.

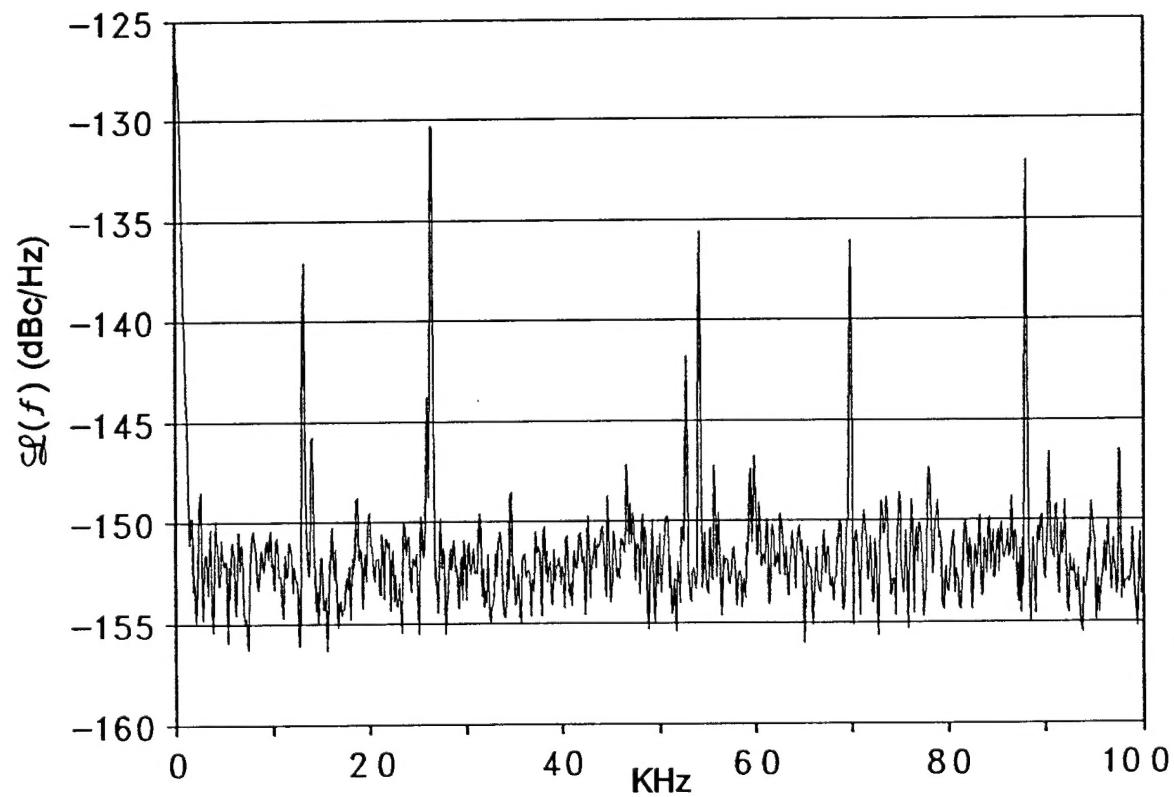


Figure C.12. Phase noise to 100 KHz from the 5 MHz output.

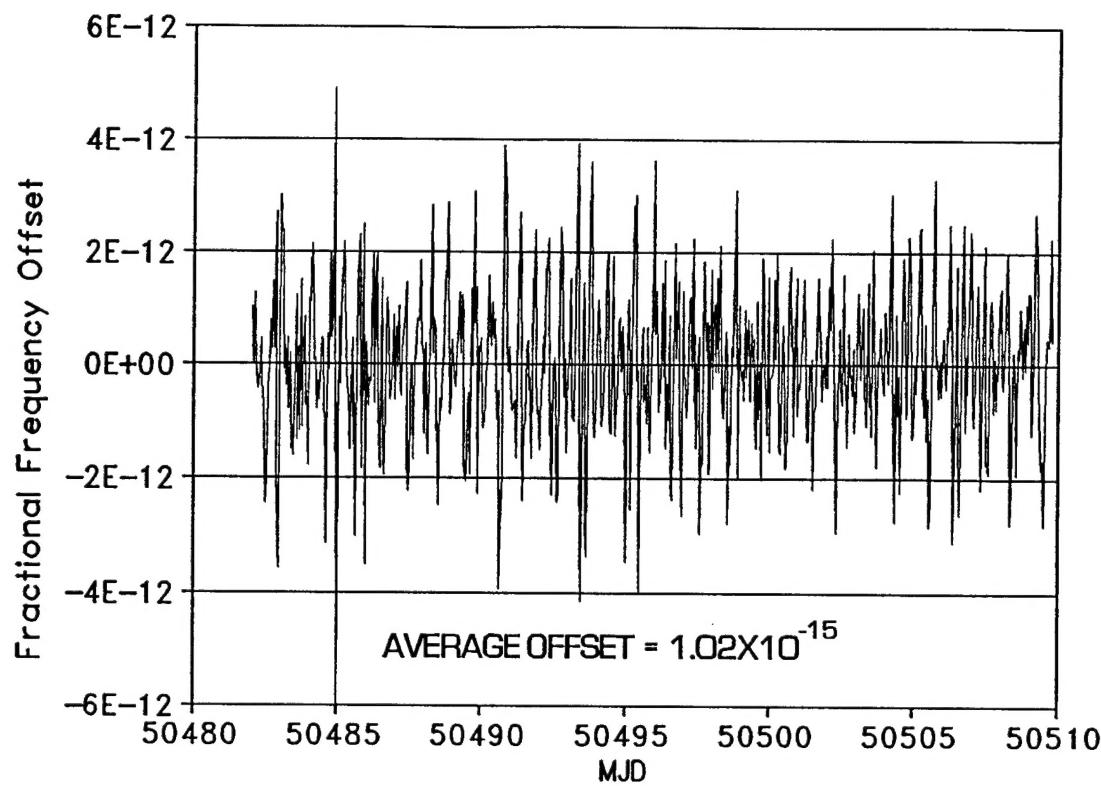


Figure C.13. Frequency offset data of the receiver's 5 MHz output.

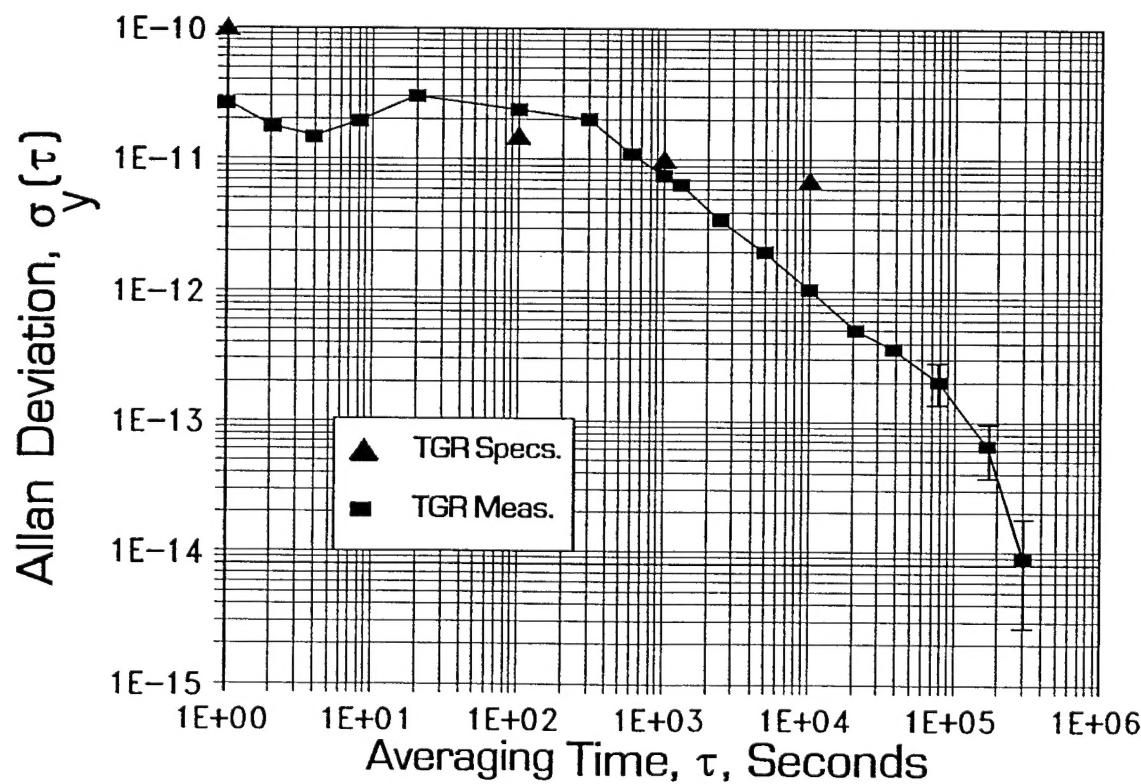


Figure C.14. Allan Deviation plot of the frequency data and specifications.

REFERENCES

1. "Navigation Systems Test Plan"; Prepared by 746th Test Squadron 46th Test Group, Holloman AFB, New Mexico 88330-7850; January 1995.
2. Frank, Alick; "GPS Receiver Test Plan"; Internal Technical Memorandum No. 96-42, NRL Space Applications Branch, Naval Research Laboratory, Washington, DC 20375; 5 June 1996.
3. "Distant Comparison of Stable Frequency Standards By Means of The Transmission of a Beat Note Between The Carrier of a Broadcast Signal and a Frequency Synthesized From The Frequency Standards"; A. Gabry, G. Faucheron, B. Duouis, P. Petit; 1 June 1977; 31st Annual Symposium on Frequency Control.
4. "System Specification For The Timing Global Positioning System (GPS) Receiver (TGR) Set"; DOC GPSR7E, Specification Num: SS-TGR-300; Code Ident: 07868; 23 Mar 1992; NAVSTAR GPS Joint Program Office.
5. Stebbins, Sarah B; "Time-Scales, offsets and Leap Seconds"; Internal Technical Memorandum No. 95-55, NRL Space Applications Branch, Naval Research Laboratory, Washington, DC 20375; 7 September 1995.